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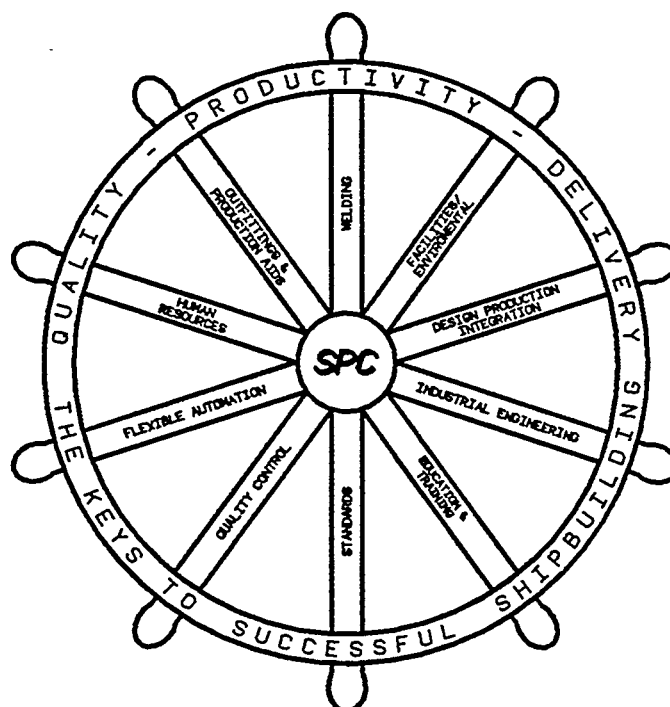
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Composites for Large Ships

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ABSTRACT

Composites, frequently referred to as fiberglass or FRP, are usually thought of as the material of choice for recreational boats. Recently though, composites have been used for 57.3 m (188 ft) minehunters and a 49 m (161 ft) yacht. Ten years ago these FRP vessels would have been at the upper limits of perceived size limitations, but practical limitations on the size of vessels using composites as the primary structural material are premature due to continuing advances in the materials and processing technology.

Composites are used for small sections of large steel vessels including non-pressure hull decking for submarines, weapons enclosures for destroyers, and funnels on cruise ships. Potential uses on large cargo vessels include bulbous bows, hatch covers, stern fairings, deck machinery enclosures and non-structural interiors. This paper reviews current usage and explores future potential on the use of composites on larger vessels.

INTRODUCTION

Generic composites are two or more distinctly different materials combined into (but not dissolved into) one structure to perform a function neither material is capable of doing singly. Steel reinforced concrete is an example where the steel carries the tensile loads and the concrete mainly compressive loads. Ferrocement yachts, power boats and barges have been built in limited numbers with limited success, because of difficult construction, weight and sweating problems. Metal matrix composites use small amounts of very high strength fibers, such as boron, in a metal matrix, such as steel or aluminum. However, due to weight or expense, these composite types are not common to bulk applications found in marine use.

Some of the many advantages of Fiber

Reinforced Plastic (FRP) are its light weight, high specific strength, ease of forming, resistance to corrosion, and long life. Some specific disadvantages are flammability, relatively low modulus, and the generation of volatile organic compounds during lamination. These factors are discussed in another section, but the advantages and disadvantages of composites have been covered by many other sources and need not be belabored here.

For common marine industry use, composites are generally a glass, Kevlar® or carbon fiber in a thermoset plastic polymer matrix. FRP is the common referring acronym. Glass Reinforced Plastic (GRP) was a frequently used term in the past, but is now out of date because of the more common use of Kevlar® and carbon. "Fiberglass" or just "glass," Reinforced Plastics (RP), and Polymer Matrix Composites (PMC) are terms still used to refer to the same group of materials. With many different types and fabric weave arrangements for the common fibers, many formulations of the basic resin types, and vastly different properties achieved from various fabrication methods, marine composites comprise an almost infinite choice of materials.

Marine composites have been used for limited applications on large steel ships, mainly on combatant types. FRP is used on submarines for flooded nose fairings, diving planes and non-pressure hull decks. A weapons enclosure prototype (1) has been developed for use on a destroyer. The OSPREY class coastal minehunters (MHCs) have their primary structure in FRP. The wood mine countermeasure vessels have numerous FRP extrusions for rails, ladders and other minor attachments, and their entire funnels are made of FRP.

Because of a U.S. regulatory requirement for steel or equivalent structure for carrying more than 149 passengers, the use of composites on commercial passenger vessels

has been limited to small passenger vessels (less than 100 gross tons) and escape craft for larger passenger vessels. The passenger load allowed on U.S. Coast Guard certified FRP small passenger vessels can be easily carried on a 27 m (87 ft) FRP monohull. Larger FRP vessels are in service and could handle more passengers. Most of these are yachts, but the MHCs and Norwegian 450 passenger surface effect ships (SESSs) demonstrate that larger FRP vessels are practical.

FRP hatch covers are used on dry cargo barges for inland transportation but are not used on ocean-going vessels. Pre-formed FRP deck gratings are used on raised catwalks on oil tankers. However, there is no extensive use of composites on ocean-going commercial vessels. Criteria for considering composites on large steel vessels in various applications

are reassessed by this paper. Limiting issues of damage tolerance, bonding and mechanical attachment strength, flammability, classification and regulation are discussed.

BASIC MATERIALS

The most commonly used composites in the marine industry are glass fibers, Kevlar® or carbon fiber in a thermoset plastic polymer matrix, generically referred to as FRP. Table I shows the raw fiber properties of some of these materials (1). However, after the materials are woven or stitched into a fabric and combined with resin, the actual properties of the finished laminate varies drastically and is quite dependent on the method of fabrication. Table II is a comparison of some of the basic

Fiber	Tensile Strength psi X 10 ³	Tensile Modulus psi X 10 ³	Ultimate Elongation	Cost U.S.\$/LB
E-glass	500	10.5	4.8%	0.80-1.20
S-glass	665	12.6	5.7%	4
Kevlar®	525	18	2.9%	16
Spectra® 900	375	17	3.5%	22
Carbon	350-700	33-57	0.38-2.0%	17-450

Table I Raw Fiber Properties

properties for an 800 gm/m² (24 oz/yd²) E-glass laminate of either woven roving (WR) or unidirectional (UNI) weave with different fabrication methods and different resins (1, 2).

One would expect the unidirectional polyester resin laminate to be much stronger than the WR polyester laminate, but the glass content referenced (2) was "approximate" and the possible differences in structural qualities of different grades of polyester resins can be significant. However, the superiority of a vinyl ester resin laminate with 70 percent glass content is obvious. Conversely, poorly done (high resin content) laminates can have very poor physical properties.

Differences in the test methods can also produce physical property data that is not directly comparable. For example, when a

simple tensile test is performed on a unidirectional laminate, the allowed variability in the sample size can cause significant differences in the test results. If the sample size is 25 mm (1 in) wide and 150 mm (6 in) long, and is cut 5 degrees off the axis of the fiber direction, half of the supposedly continuous fibers are cut off. A 150 mm (6 in) wide by 300 mm (12 in) sample cut with the same 5 degree error would only have 8.7 per cent of its fibers cut. Standardizing the standard test methods is a project of great interest to the FRP industry, the Coast Guard, the American Bureau of Shipping (ABS) and the Navy, and is being addressed by the Society of Naval Architects and Marine Engineer's (SNAME) Panel HS-9, Hull Structural Materials.

PROPERTY	WET LAYUP 50% POLY WR	WET LAYUP 50% POLY UNI	SCRIMP 70% POLY WR	SCRIMP 70% V.E. WR
TENSILE STRENGTH (ksi)	46.8	35	67.3	70.9
TENSILE MODULUS (msi)	3.2	2.2	4.5	4.6
COMPRESSIVE STRENGTH (ksi)	39.1	37	42.1	68.6
FLEXURAL STRENGTH (ksi)	52.2	65	66.8	90.0
INTERLAMINAR SHEAR STRENGTH (ksi)	3.3	NA	4.5	7.3

50% or 70%= % glass content by weight, POLY = polyester resin, V.E. = vinyl ester resin
SCRIMP™ = Seemann Composites Resin Infusion Molding Process

Table II Laminate Properties

EXISTING COMPOSITES APPLICATIONS

The widespread use of composites, mostly FRP, in various parts of the marine industry is still not well known or understood in the world of large steel ships. The difficulties encountered with the Navy's "Integrated Technology Deckhouse Project" (3) demonstrate this. Some of those difficulties were a reluctance to deal with any processing of the panels, mechanical and adhesive fastening of the FRP-steel joints, and attachment of outfitting items. However, current applications of marine type composites (as opposed to high technology high cost aerospace composites) in Navy and commercial projects seem to indicate a change in thinking, and serve to justify the further application on commercial vessels.

Most notable of large scale FRP applications is in the OSPREY class MHCs being built by both Intermarine and Avondale. These vessels are 57.3 m (188 ft) long, and are built of a specially developed spun woven roving laminated with impregnators into a sectional steel mold. They are heavily constructed monocoque structures with a 76 mm (3 in) thick single skin laminate (200 mm (8 in) at the keel) to take severe underwater blasts, and are naturally anti-magnetic. Although the specialized nature of the MHCs is not likely to support a direct transfer of

composites technology to commercial vessels, their existence indicates what can be done.

In July of this year the 49 m (161 ft) sandwich composite yacht EVIVVA was launched by Admiral Marine in Port Townsend, Washington. This vessel is significant in that it is the largest non-military sandwich composite vessel yet built; it embodies the best qualities of composites in that it is light weight and structurally robust. Cores used in its sandwich structure consist of

- damage tolerant linear PVC foam bottom and side shell,
- high density acrylic co-polymer foam for the keel and engine girders, and
- cross-linked PVC foam for decks and deckhouse.

Because of the yacht quality finish, extensive use of honeycomb for light weight joiner work and interior cabinetry (4), and three year build time, this yacht is not likely to directly justify use of FRP for similarly sized commercial vessels. However, it shows that an FRP vessel of this size is feasible. This vessel was constructed using relatively low cost wood one-off female molds. It would have placed 91st in last year's listing of the 100 largest yachts (5); only one other yacht was FRP, four were aluminum, and the rest were steel.

Of more immediate interest for commercial shipbuilding are the efforts of

Italian shipbuilder Fincantieri, which is actively using composites in shipbuilding (6). They are focusing mainly on weight reduction and stability effects, but they are also trying to minimize the use of light alloy, reduce cost, cut maintenance and improve aesthetics. They have used FRP for funnels on two large classes of cruise liners, for various piping applications, and they are doing research in collaboration with classification societies to use more composites in deckhouses.

One of the Fincantieri FRP funnel installations is a triple stack design for two cruise ships in the Costa Crociere Line. Each funnel is an elliptical FRP sandwich structure 3 m x 5 m x 12 m (10 x 16 x 40 ft) and was designed to withstand a 100 knot wind and inertial loads. Savings were on the order of 50 per cent for weight and 20 per cent on cost compared to the aluminum and stainless steel structures they replaced. In addition, the appearance of the FRP funnels is more to the owner's satisfaction.

Another of their stack designs is on three Holland America Line cruise ships. This is a large single stack design with FRP panels attached to a steel frame. The owner's logo is molded into the side panels. The logo molds are also used for creating decorative FRP panels which are fitted to other parts.

Use of FRP pipe for non-critical applications on all classes of commercial vessels is relatively commonplace, but still requires mention here. As early as 1976 (7) the NSRP evaluated use of FRP pipe and reported savings of 15 to 20 per cent in cost; because at that time FRP pipe was more expensive than steel, the savings was mostly related to installation labor, ease of handling due to the lighter weight, and ease of joining due to adhesive bonded joints. However, life cycle cost gains were expected in the areas of corrosion and pumping efficiency. Problems were encountered in making custom bends, valve support and hanger design. Current application experience has eliminated most of these problems.

Crucial to the widespread application of composites in U.S. commercial and auxiliary vessel construction will be the U.S. Navy's treatment of composites, and the confidence that the Navy builds with shipbuilders in using FRP. Four application areas demonstrate that the Navy is advancing its use of composites:

- continuing work on deckhouse projects,
- the Mark V patrol boat
- projects on the R&D submarine, and
- the new standard landing craft program.

The various composite deckhouse programs (3, 8) are being conducted to support replacement of aluminum deckhouses in surface combatants due to cost, fabrication and fire problems that are associated with aluminum. This seems unusual, since one of the major problems with composites is their behavior in fire and elevated temperature environments. Composites have a relatively low heat distortion temperature, burn, and give off toxic gases. However, composites do not readily transmit heat, can easily be coated to enhance their fire resistance, and exhibit better overall structural integrity than similar structures of aluminum. The advantages still outweigh the disadvantages, and FRP remains a viable alternative as research continues.

In the Navy's Mark V patrol boat procurement, one FRP and two aluminum prototypes will be built and evaluated in early 1994. The Equitable yard of Trinity Marine, with U.S. Marine building the sandwich hulls, will build the FRP vessel which is a 25 m (82 ft) monohull capable of 50 knots. This is the Navy's largest FRP performance craft (besides the "stealth" SEA SHADOW) to date.

The use of composites in the U.S. Navy's research and development (R&D) submarine, the USS MEMPHIS, demonstrates the extent of forward thinking involved in the program (9). At that time (two years ago), the following items were scheduled for implementation and are believed to have been executed

- main propulsion shafting,
- various machinery foundations,
- air flasks,
- control surfaces,
- sail, and
- the stem structure.

Future candidates in the same program include:

- ballast tanks,
- piping and ducting,
- machinery
- storage tanks,
- decks and hatches, and
- hydrodynamic fairings.

Solid single skin laminates are already in fleet use for the nose sections on submarines.

The Germans are already using sandwich composite, non-pressure hull, deck structures on their subs. The structural foam in the sandwich is a high density (400 kg/m³ [24 lb/ft³]) acrylic co-polymer foam that is also used in parts of deep diving submersibles. With submarines being weight sensitive, and with the amount of distortion, fairing and noise isolation that is involved with current thin plate high strength steel construction of these deck structures, this application area should yield very favorable results on U.S. subs.

The Advanced Material Transporter (AMT) is being developed by the U.S. Navy, partly as a replacement for aging utility landing craft (LCU), but more to be complimentary to the air cushion landing craft (LCAC) (2). It is designed to carry 81 t (90 short tons) of cargo at 20 knots in sea state 3 on a 34 m (111.7 ft) hull. Its basic design is a solid FRP bottom and side shell with a balsa cored deck and deckhouse. A one third scale validation model has been constructed using the Seemann Composites Resin Infusion Molding Process (SCRIMPTM) method, which the Navy calls the Vacuum Assisted Resin Transfer Molding (VARTM) process. The process yields the very high physical properties shown in Table II without the need for matched molds, a requirement for most RTM processes. The developers of this craft have stated that it was difficult to convince the littoral warfare people in the Navy and Marine Corps to accept a composite craft, but the fact that this program is proceeding is an indication that composites have an improved image in the minds of military decision makers.

Additional developments in naval applications of composites (9) include:

- weapons enclosures,
- gun enclosures,
- rudders,
- dry deck shelters,
- missile blast shields,
- ladders,
- deck drains,
- rails,
- radomes,
- hatches,
- masts, and
- stacks.

LARGE COMMERCIAL SHIP APPLICATIONS

An old but still relevant report by the Ship Structures Committee (SSC) (10) investigated the possibility of constructing a 143 m (470 ft) cargo vessel of FRP. Most of the design exercise was done as a direct conversion of the existing steel vessel.

The FRP vessel that resulted from this study was not optimized to increase the moment of inertia of the midships section, so using a material tensile modulus (the compressive modulus is nearly the same) of only 2×10^4 MPa (2.9×10^6 psi), deflections of the hull girder were five times that of the steel structure. The report theorized that a deflection of two times that of steel would have been acceptable. However, with use of available modern materials and fabrication methods, this deflection limit could be met. With increased use of unidirectional material applied by the SCRIMPTM or a high efficiency impregnator (11), a 3.8×10^4 MPa (5.5×10^6 psi) tensile modulus is possible. If the midships section is optimized for maximum moment of inertia, by reducing hatch size or increasing the depth 10 per cent, the result is a bending stiffness half that of the steel vessel.

A number of other limitations listed in the SSC report have been overcome by materials presently available. Table III compares these former limitations to current solutions.

One point made by the SSC report was that cored laminates were not feasible due to high cost of purchase and installation. It correctly stated that balsa cored laminates should not be used in the hull, however, these laminates are very inexpensive compared to equivalent single skin laminates, and quite applicable to interior structure, especially for fire resistant divisions. Polyvinyl chloride foams are nearly two to three times as expensive as balsa, but they could be used in a number of applications that would make a large FRP vessel significantly lighter and less expensive to construct. The SSC report predicted that the use of a sandwich laminate would not be an advantage in the middle portions of the ship due to the need for a large cross sectional area of continuous FRP to keep the midships section stiff. However, use of a sandwich laminate outside the middle 40 per cent of the length is feasible.

LIMITATION	OLD ARGUMENT	CURRENT SOLUTION
HULL STIFFNESS	Only 20% of steel	Increase I, better fabrication, unidirectional fabrics
ABRASION	Low resistance relative to cargo handling, bottom scraping	Kevlar [®] felt
FUEL TANKS	Laminate flaws allowed fuel to seep into the structure in integral tanks	Use of two layers of mat and a veil with V.E. resin adequate for sealing integral tanks
LAYUP	Hand layup inadequate, impregnators not developed	Impregnators well developed, SCRIMP [™] or equivalent under development
SECONDARY BONDS	Weakest part of technology	Well developed guidelines now in place, can be made strong
FIRE RESISTANCE	Resins subject to fire, fire retardant (FR) resins expensive and weak	Modern FR resins much better and reasonably priced, FR coatings available

Table III Perceived limitations of FRP in ships.

The SSC report also identified highly shaped bow and stern sections as being feasible based on cost and weight, regardless of whether the ship behind these sections are steel or FRP. Large bulbous bows are very difficult to shape in steel and even harder to fabricate by welding, especially the inside structure. The cost advantage of FRP bows over steel is greater than that reported if the following construction scheme (prescribed by Johannsen 20 years ago [12]) is followed.

1. Construct a wooden male batten frame 25 mm (1 in) inside the desired molded line, arranged with a 12 to 1 scarfed joint.
2. Cover with a damage tolerant linear PVC foam, heat formed to achieve extreme curvatures, attached from the inside by wood screws.
3. Laminate an 8 mm (0.31 in) FRP outer skin.
4. Back out screws to detach foam from frame, lay part in cradle.
5. Bond in second layer of 25 mm (1 in) foam and laminate an 8 mm (0.31 in) FRP inner skin.
6. Repeat the process for the mirror image opposite side.

7. Bond the two halves together.
8. Laminate the joints, fair, and gelcoat.

Admittedly, this is a simplified scenario, but it has been used for a number of other projects ranging from custom boats to large decorative architectural works. The same procedure could be used for the whole bow or stern section to eliminate some of the hardest to form and weld curved panels in shipbuilding.

The flammability issue is one that has always plagued FRP construction in general and marine use in particular, especially in terms of passenger vessels. However, the Coast Guard has been considering the use of composites on small passenger vessels for five years and has recently given tentative concept approval for a vessel with a large amount of the structure made of FRP. The Coast Guard has also been doing research on fire retardant coatings applied to FRP.

Although there are many other issues to be considered in the use of composites in large ships, one last issue that frequently surfaces is attaching FRP to steel. This was addressed in the Navy's deckhouse projects by using a combination of bonding and bolting (3). Although the bond strength of an aggressive

vinyl ester resin to steel is on the order of 9650 Pa (1400 psi) (13), further Navy research has shown that bonding alone is not adequate to resist nuclear air blasts and combination joints are required. In more normal applications, bonding has proven adequate to completely cover the underwater hull of an aging steel hull with a new sandwich composite shell (14). Therefore, attachments of FRP to steel or aluminum should not be considered a barrier to using FRP with metals in marine construction.

The Coast Guard, the American Bureau of Shipping (ABS), and other regulatory agencies and classification societies are steadily improving their rules and positions relative to composites, and are open to new ideas.

CONCLUSIONS

Arguments for and against the use of composites in various marine applications have been advanced before. Generally, as the age of the argument grows, its validity wanes. Marine type composites have been applied to advanced projects ranging from large and very expensive yachts, to highly loaded utilitarian landing craft, to submarine nose cones. Common use of composites for commercial vessels is feasible and should be pursued.

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